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Activity Report 2011

Project-Team OPALE

Optimization and control, numerical algorithms and integration of complex multidisciplinary systems governed by PDE

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

RESEARCH CENTERS
Sophia Antipolis - Méditerranée
Grenoble - Rhône-Alpes

THEME
Computational models and simulation

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Project-Team OPALE

Keywords: Scientific Computation, Model Coupling, Shape Optimization

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2. Overall Objectives

2.1. Research fields

Optimizing a complex system arising from physics or engineering covers a vast spectrum in basic and applied sciences. Although we target a certain transversality from analysis to implementation, the particular fields in which we are trying to excell can be defined more precisely.

From the *physical analysis* point of view, our expertise relies mostly on Fluid and Structural Mechanics and Electromagnetics. In the former project Sinus, some of us had contributed to the basic understanding of fluid mechanical phenomena (Combustion, Hypersonic Non-Equilibrium Flow, Turbulence). More emphasis is now given to the coupling of engineering disciplines and to the validation of corresponding numerical methodologies.

From the *mathematical analysis* point of view, we are concerned with functional analysis related to partial-differential equations, and the functional/algebraic analysis of numerical algorithms. Identifying the Sobolev space in which the direct or the inverse problem makes sound sense, tailoring the numerical method to it, identifying a functional gradient in a continuous or discrete setting, analyzing iterative convergence, improving it, measuring multi-disciplinary coupling strength and identifying critical numerical parameters, etc constitute a non-exhaustive list of mathematical problems we are concerned with.

Regarding more specifically the *numerical aspects* (for the simulation of PDEs), considerable developments have been achieved by the scientific community at large, in recent years. The areas with the closest links with our research are:

1. *approximation schemes*, particularly by the introduction of specialized Riemann solvers for complex hyperbolic systems in Finite-Volume/Finite-Element formulations, and highly-accurate approximations (e.g. ENO schemes),
2. *solution algorithms*, particularly by the multigrid, or multilevel and multi-domain algorithms best-equiped to overcome numerical stiffness,
3. *parallel implementation and software platforms*.

After contributing to some of these progresses in the former project Sinus, we are trying to extend the numerical approach to a more global one, including an optimization loop, and thus contribute, in the long-term, to modern scientific computing and engineering design. We are currently dealing mostly with *geometrical optimization*.

Software platforms are perceived as a necessary component to actually achieve the computational cost-efficiency and versatility necessary to master multi-disciplinary couplings required today by size engineering simulations.

2.2. Objectives

The project has several objectives: to analyze mathematically coupled PDE systems involving one or more disciplines in the perspective of geometrical optimization or control, to construct, analyze and experiment numerical algorithms for the efficient solution of PDEs (coupling algorithms, model reduction), or multi-criterion optimization of discretized PDEs (gradient-based methods, evolutionary algorithms, hybrid methods, artificial neural networks, game strategies), to develop software platforms for code-coupling and for parallel and distributed computing.

Major applications include : the multi-disciplinary optimization of aerodynamic configurations (wings in particular) in partnership with the French or European aeronautical industry and research (Airbus, Dassault Aviation, ONERA, etc), the geometrical optimization of antennas in partnership with France Télécom and Thalès Air Défense (see Opratel Virtual Lab.), the development of *Collaborative, Distributed and High-Performance environments in collaboration with Chinese partners (CAE).*

2.3. Highlights

Our activity in road traffic modeling is reinforced by the doctoral thesis of M. L. Delle Monache, started in October.

Our collaboration with the SME K-Epsilon is fostered by two new contracts in the area of naval research (see Section 7.2).

3. Scientific Foundations

3.1. Functional and numerical analysis of PDE systems

Our common scientific background is the functional and numerical analysis of PDE systems, in particular with respect to nonlinear hyperbolic equations such as conservation laws of gas-dynamics.

Whereas the structure of weak solutions of the Euler equations has been thoroughly discussed in both the mathematical and fluid mechanics literature, in similar hyperbolic models, focus of new interest, such as those related to traffic, the situation is not so well established, except in one space dimension, and scalar equations. Thus, the study of such equations is one theme of emphasis of our research.

The well-developed domain of numerical methods for PDE systems, in particular finite volumes, constitute the sound background for PDE-constrained optimization.

3.2. Numerical optimization of PDE systems

Partial Differential Equations (PDEs), finite volumes/elements, geometrical optimization, optimum shape design, multi-point/multi-criterion/multi-disciplinary optimization, shape parameterization, gradient-based/evolutionary/hybrid optimizers, hierarchical physical/numerical models, Proper Orthogonal Decomposition (POD)

Optimization problems involving systems governed by PDEs, such as optimum shape design in aerodynamics or electromagnetics, are more and more complex in the industrial setting.

In certain situations, the major difficulty resides in the costly evaluation of a functional by means of a simulation, and the numerical method to be used must exploit at best the problem characteristics (regularity or smoothness, local convexity).

In many other cases, several criteria are to be optimized and some are non differentiable and/or non convex. A large set of parameters, sometimes of different types (boolean, integer, real or functional), are to be taken into account, as well as constraints of various types (physical and geometrical, in particular). Additionally, today's most interesting optimization pre-industrial projects are multi-disciplinary, and this complicates the mathematical, physical and numerical settings. Developing *robust optimizers* is therefore an essential objective to make progress in this area of scientific computing.

In the area of numerical optimization algorithms, the project aims at adapting classical optimization methods (simplex, gradient, quasi-Newton) when applicable to relevant engineering applications, as well as developing and testing less conventional approaches such as Evolutionary Strategies (ES), including Genetic or Particle-Swarm Algorithms, or hybrid schemes, in contexts where robustness is a very severe constraint.

In a different perspective, the heritage from the former project Sinus in Finite-Volumes (or -Elements) for nonlinear hyperbolic problems, leads us to examine cost-efficiency issues of large shape-optimization applications with an emphasis on the PDE approximation; of particular interest to us:

- best approximation and shape-parameterization,
- convergence acceleration (in particular by multi-level methods),
- model reduction (e.g. by *Proper Orthogonal Decomposition*),
- parallel and grid computing; etc.

3.3. Geometrical optimization

Jean-Paul Zolesio and Michel Delfour have developed, in particular in their book [4], a theoretical framework for for geometrical optimization and shape control in Sobolev spaces.

In preparation to the construction of sound numerical techniques, their contribution remains a fundamental building block for the functional analysis of shape optimization formulations.

3.4. Integration platforms

Developing grid computing for complex applications is one of the priorities of the IST chapter in the 6th Framework Program of the European Community. One of the challenges of the 21st century in the computer science area lies in the integration of various expertise in complex application areas such as simulation and optimization in aeronautics, automotive and nuclear simulation. Indeed, the design of the reentry vehicle of a space shuttle calls for aerothermal, aerostructure and aerodynamics disciplines which all interact in hypersonic regime, together with electromagnetics. Further, efficient, reliable, and safe design of aircraft involve thermal flows analysis, consumption optimization, noise reduction for environmental safety, using for example aeroacoustics expertise.

The integration of such various disciplines requires powerful computing infrastructures and particular software coupling techniques. Simultaneously, advances in computer technology militate in favor of the use of massively parallel PC-clusters including thousands of processors connected by high-speed gigabits/sec wide-area networks. This conjunction makes it possible for an unprecedented cross-fertilization of computational methods and computer science. New approaches including evolutionary algorithms, parameterization, multi-hierarchical decomposition lend themselves seamlessly to parallel implementations in such computing infrastructures. This opportunity is being dealt with by the OPALE project since its very beginning. A software integration platform has been designed by the OPALE project for the definition, configuration and deployment of multidisciplinary applications on a distributed heterogeneous infrastructure. Experiments conducted within European projects and industrial cooperations using CAST have led to significant performance results in complex aerodynamics optimization test-cases involving multi-elements airfoils and evolutionary algorithms, i.e. coupling genetic and hierarchical algorithms involving game strategies [62].

The main difficulty still remains however in the deployment and control of complex distributed applications on grids by the end-users. Indeed, the deployment of the computing grid infrastructures and of the applications in such environments still requires specific expertise by computer science specialists. However, the users, which are experts in their particular application fields, e.g. aerodynamics, are not necessarily experts in distributed and grid computing. Being accustomed to Internet browsers, they want similar interfaces to interact with grid computing and problem-solving environments. A first approach to solve this problem is to define component-based infrastructures, e.g. the Corba Component Model, where the applications are considered as connection networks including various application codes. The advantage is here to implement a uniform approach for both the underlying infrastructure and the application modules. However, it still requires specific expertise not directly related to the application domains of each particular user. A second approach is to make use of grid services, defined as application and support procedures to standardize access and invocation to remote support and application codes. This is usually considered as an extension of Web services to grid infrastructures. A new approach, which is currently being explored by the OPALE project, is the design of a virtual computing environment able to hide the underlying grid-computing infrastructures to the users.

4. Application Domains

4.1. Aeronautics and space

The demand of the aeronautical industry remains very strong in aerodynamics, as much for conventional aircraft, whose performance must be enhanced to meet new societal requirements in terms of economy, noise (particularly during landing), vortex production near runways, etc., as for high-capacity or supersonic aircraft of the future. Our implication concerns shape optimization of wings or simplified configurations.

Our current involvement with Space applications relates to software platforms for code coupling.

4.2. Mechanical industry

A new application domain related to the parameter and shape optimization of mechanical structures is under active development. The mechanical models range from linear elasticity of 2D or 3D structures, or thin shells, to nonlinear elastoplasticity and structural dynamics. The criteria under consideration are multiple: formability, stiffness, rupture, fatigue, crash, and so on. The design variables are the thickness and shape, and possibly the topology, of the structures. The applications are performed in collaboration with world-leading industrials, and involve the optimization of the stamping process (Blank Force, Die and Tools shapes) of High Performance steel structures as well as the optimal design of structures used for packaging purposes (cans and sprays under high pressure). Our main contribution relies on providing original and efficient algorithms to capture Pareto fronts, using smart meta-modelling, and to apply game theory approaches and algorithms to propose stable compromise solutions (e.g. Nash equilibria).

4.3. Electromagnetics

In the context of shape optimization of antennas, we can split the existing results in two parts: the two-dimensional modeling concerning only the specific transverse mode TE or TM, and treatments of the real physical 3-D propagation accounting for no particular symmetry, whose objective is to optimize and identify real objects such as antennas.

Most of the numerical literature in shape optimization in electromagnetics belongs to the first part and makes intensive use of the 2-D solvers based on the specific 2-D Green kernels. The 2-D approach for the optimization of *directivity* led recently to serious errors due to the modeling defect. There is definitely little hope for extending the 2-D algorithms to real situations. Our approach relies on a full analysis in unbounded domains of shape sensitivity analysis for the Maxwell equations (in the time-dependent or harmonic formulation), in particular, by using the integral formulation and the variations of the Colton and Kreiss isomorphism. The use of the France Telecom software SR3D enables us to directly implement our shape sensitivity analysis in the harmonic approach. This technique makes it possible, with an adequate interpolation, to retrieve the shape derivatives from the physical vector fields in the time evolution processes involving initial impulses, such as radar or tomography devices, etc. Our approach is complementary to the "automatic differentiation codes" which are also very powerful in many areas of computational sciences. In Electromagnetics, the analysis of hyperbolic equations requires a sound treatment and a clear understanding of the influence of space approximation.

4.4. Biology and medicine

A particular effort is made to apply our expertise in solid and fluid mechanics, shape and topology design, multidisciplinary optimization by game strategies to biology and medicine. Two selected applications are privileged: solid tumors and wound healing.

Opale's objective is to push further the investigation of these applications, from a mathematical-theoretical viewpoint and from a computational and software development viewpoint as well. These studies are led in collaboration with biologists, as well as image processing specialists.

4.5. Traffic flow

The modeling and analysis of traffic phenomena can be performed at a macroscopic scale by using partial differential equations derived from fluid dynamics. Such models give a description of collective dynamics in terms of the spatial density $\rho(t, x)$ and average velocity $v(t, x)$. Continuum models have shown to be in good agreement with empirical data. Moreover, they are suitable for analytical investigations and very efficient from the numerical point of view. Finally, they contain only few variables and parameters and they can be very versatile in order to describe different situations encountered in practice.

Opale's research focuses on the study of macroscopic models of vehicular and pedestrian traffic, and how optimal control approaches can be used in traffic management. The project opens new perspectives of inter-disciplinary collaborations on urban planning and crowd dynamics analysis.

4.6. Multidisciplinary couplings

Our expertise in theoretical and numerical modeling, in particular in relation to approximation schemes, and multilevel, multi-scale computational algorithms, allows us to envisage to contribute to integrated projects focused on disciplines other than, or coupled with fluid dynamics, such as structural mechanics, electromagnetics, biology and virtual reality, image processing, etc in collaboration with specialists of these fields. Part of this research is conducted in collaboration with ONERA.

5. Software

5.1. NUM3SIS

Participants: Régis Duvigneau [correspondant], Thibaud Kloczko, Nora Aïssiouene.

NUM3SIS (http://num3sis.inria.fr) is a modular platform devoted to scientific computing and numerical simulation. It is not restricted to a particular application field, but is designed to host complex multidisciplinary simulations. Main application fields are currently Computational Fluid Dynamics (CFD), Computational Electro-Magnetics (CEM, in collaboration with Nachos Project-Team) and pedestrian traffic simulation.
The most important concept in NUM3SIS is the concept of node. It is a visual wrapper around derivatives of fundamental concepts such as data, algorithm or viewer. Atomic nodes are provided for convenience in order to manipulate computational data (such as grids or fields), apply computational methods (such as the building of a finite-element matrix or the construction of a finite-volume flux) and visualize computational results (such as vector or tensor fields, on a screen or in an immersive space). For a given abstract node, different implementations can be found, each of them being embedded in a plugin system that is managed by a factory.

The second important concept in NUM3SIS is the concept of composition. It consists of the algorithmic pipeline used to link the nodes together. The use of these two concepts, composition and nodes, provides a highly flexible, re-usable and efficient approach to develop new computational scenarii and take benefit from already existing tools. This is a great advantage with respect to classical monolithic softwares commonly used in these fields.
This work is being carried out with the support of two engineers in the framework of an ADT (Action de Développement Technologique) program.

5.2. FAMOSA

Participant: Régis Duvigneau [correspondant].

Opale team is developing the software platform FAMOSA (C++), that is devoted to multidisciplinary design optimization in engineering. It integrates the following components:

- an optimization library composed of various algorithms : several descent methods from steepest-descent method to quasi-Newton BFGS method (deterministic, smooth), the Multi-directional Search Algorithm (deterministic, noisy), the Covariance Matrix Adaption Evolution Strategy (semi-stochastic, multi-modal) and the Efficient Global Optimization method (deterministic, multi-modal). It also contains the Pareto Archived Evolution Strategy to solve multi-objective optimization problems ;
- an evaluation library managing the performance estimation process (communication with external simulation tools) ;

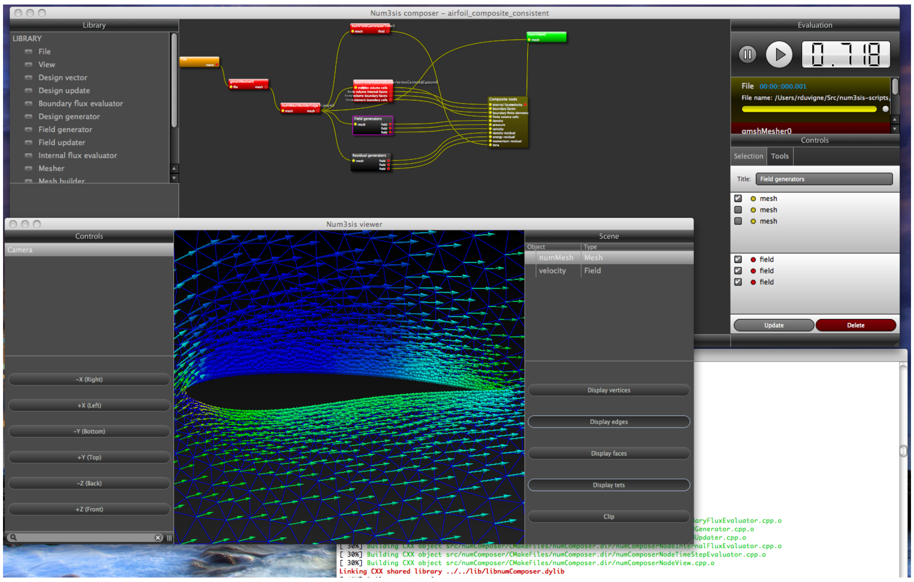

Figure 1. Illustration of the graphic user interface of the NUM3SIS platform: at the top the composition space, at the bottom the visualization space.

- a metamodel library that contains tools to build a database and kriging models that are used to approximate the objective function for different purposes;
- a scenario library that allows to use the previous components to achieve various tasks:
  - Construct a design of experiments ;
  - Construct a metamodel ;
  - Find the design that minimizes a cost functional ;
  - Find the Pareto front for two cost functionals
  - Play a Nash game to find the equilibrium between two criteria ;
  - Apply a multiple gradient descent strategy to improve simultaneously two criteria.

The FAMOSA platform is employed by Opale Project-Team to test its methodological developments in multidisciplinary design optimization (MDO). The platform is also used by the Fluid Mechanics Laboratory at Ecole Centrale de Nantes and by the K-Epsilon company (http://www.k-epsilon.com) for hydrodynamic design applications. Moreover, it is presently tested by Peugeot Automotive industry for external aerodynamic design purpose.

5.3. Plugins for AXEL

Participants: Régis Duvigneau [correspondant], Louis Blanchard.

Opale team is developing plugins in the framework of the algebraic modeler Axel, in collaboration with GALAAD team. These developments correspond to two research axes :

- methods for isogeometric analysis and design. In particular, two simulation tools for heat conduction and compressible flows have been implemented, in conjunction with some deterministic and semi-stochastic optimization algorithms for optimum-shape design ;
- methods for geometrical modeling of bow shapes for trawler ships.

5.4. Integration platform for multidiscipline optimization applications

Participants: Toan Nguyen, Laurentiu Trifan.

A prototype software integration platform is developed and tested for multidiscipline optimization applications. It is based on a workflow management system called YAWL (http://www.yawlfoundation.org). The goal is to design, develop and assess high-performance distributed scientific workflows featuring resilience, fault-tolerance and exception-handling capabilities. The platform is used to experiment new resilience algorithms, including monitoring and management of application-level errors. The platform is tested against use-cases provided by the industry partners in the OMD2 project supported by the French Agence Nationale de la Recherche. This work is part of Laurentiu Trifan's PhD thesis. (See Fig. 2.)

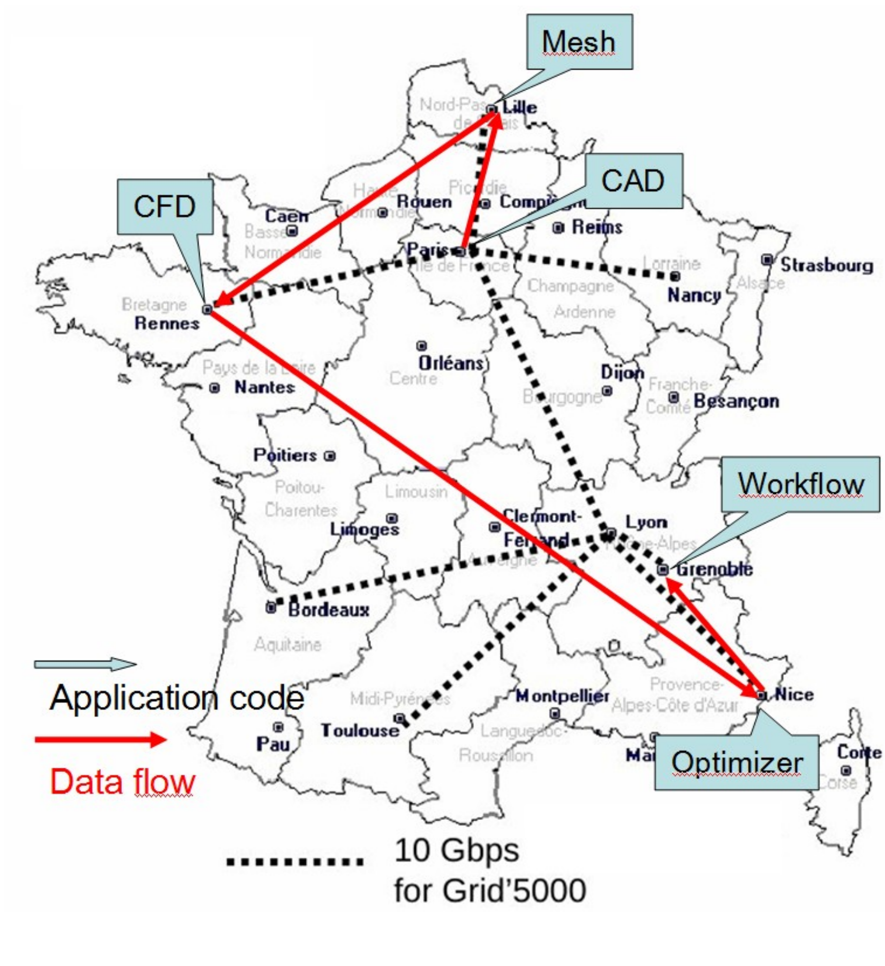

Figure 2. Testcase deployment on the Grid5000 infrastructure.

6. New Results

6.1. Mathematical analysis and control of macroscopic traffic flow models

6.1.1. Vehicular traffic

Participants: Maria Laura Delle Monache, Paola Goatin, Mauro Garavello [Piedmont University, Italy].

Concerning road traffic, the research activity during 2011 focused on the mathematical analysis of traffic flow models on road networks or subject to unilateral constraints. In particular, [34] is devoted to a hyperbolic 2nd order model for traffic flow with local flux constraint. We describe two admissible Riemann solvers and we construct ad hoc finite volume numerical schemes to compute these solutions. The paper [59] is devoted to the study of a traffic flow model on a network composed by an arbitrary number of incoming and outgoing arcs connected together by a node with a buffer. We define the solution to the Riemann problem at the node and we prove existence and well posedness of solutions to the Cauchy problem. Finally, a general traffic flow model with phase-transition is proposed and described in [28].

M.L. Delle Monache just started her doctoral thesis in the same topic. More precisely she will study hyperbolic models of traffic flow and associated optimization problems.

6.1.2. Crowd motion

Participants: Nora Aïssiouene, Régis Duvigneau, Nader El Khatib, Jihed Joobeur, Paola Goatin, Massimiliano D. Rosini [ICM, Warsaw University, Poland].

Concerning pedestrian motion modeling, we are interested in the optimization of facilities design, in order to maximize pedestrian flow and avoid or limit accidents due to panic situations. To this aim, we are now studying a macroscopic model for crowd movements consisting in a scalar conservation law accounting for mass conservation coupled with an Eikonal equation giving the flux direction depending on the density distribution. From the theoretical point of view, and as a first step, we are studying the problem in one space dimension (for applications, this case corresponds to a crowd moving in a corridor). In collaboration with M. Rosini (supported by the project CROM3, funded by the PHC Polonium 2011), we have established entropy conditions to select physically relevant solutions, and we have constructed explicit solutions for some simple initial data (these results are presented in [54]). We are now studying existence and uniqueness of solutions of the corresponding initial boundary value problem. From the numerical point of view, we are implementing the model in two space dimensions on triangular meshes on the Num3sis platform. This was partly done by N. El-Khatib (postdoc at INRIA from January to August 2011), and will be completed soon by Nora Aïssiouene. This will provide a performing numerical tool to solve the related optimization problems arising in the optimization of facilities design, such as the position and size of an obstacle in front of (before) a building exit in order to maximize the outflow through the door and avoid or limit over-compression. Moreover, jointly with the PULSAR team, we have supervised J. Joobeur's internship, which was devoted to pedestrian data collection from real-word video recordings (Turin metro station). The density data will serve to validate the model.

The above researches were partially funded by the ERC Starting Grant "TRAM3 - Traffic management by macroscopic models".

6.2. Optimum design in fluid dynamics and its couplings

In computational sciences for physics and engineering, Computational Fluid Dynamics (CFD) are playing one of the major roles in the scientific community to foster innovative developments of numerical methodologies. Very naturally, our expertise in compressible CFD has led us to give our research on numerical strategies for optimum design a particular, but not exclusive focus on fluids.

6.2.1. Cooperation and competition in multidisciplinary optimization

Participants: Étienne Baratchart [ENSEIBB MATMÉCA], Jean-Antoine Désidéri, Régis Duvigneau, Adrien Zerbinati.

The framework of our research aims to contribute to numerical strategies for PDE-constrained multiobjective optimization, with a particular emphasis on CPU-demanding computational applications in which the different criteria to be minimized (or reduced) originate from different physical disciplines that share the same set of design variables. These disciplines are often fluids, as a primary focus, coupled with some other discipline, such as structural mechanics.

Our approach to *competitive optimization* is based on a particular construction of *Nash games*, relying on a *split of territory* in the assignment of individual strategies. A methodology has been proposed for the treatment of two-discipline optimization problems in which one discipline, the primary discipline, is preponderant, or fragile. Then, it is recommended to identify, in a first step, the optimum of this discipline alone using the whole set of design variables. Then, an orthogonal basis is constructed based on the evaluation at convergence of the Hessian matrix of the primary criterion and constraint gradients. This basis is used to split the working design space into two supplementary subspaces to be assigned, in a second step, to two virtual players in competition in an adapted Nash game, devised to reduce a secondary criterion while causing the least degradation to the first. The formulation has been proved to potentially provide a set of Nash equilibrium solutions originating from the original single-discipline optimum point by smooth continuation, thus introducing competition gradually. This approach has been demonstrated over a testcase of aero-structural aircraft wing shape optimization, in which the eigen-split-based optimization reveals clearly superior [33].

While the two-discipline method is currently being applied to various complex physical multiobjective situations (see in particular 6.2.2, 6.2.6, 6.2.7, 6.2.8), the method has been extended to situations involving more than two objectives when the initial point is Pareto-optimal. Then, a particular convex combination of the criteria is locally stationary, and the two-discipline strategy can be applied using this combination as preponderant criterion, and a particular other criterion as secondary one. Whence, the proposed split of territory produces a continuum of Nash equilibrium points *tangent* to the Pareto set. This theoretical result has been illustrated in the context of a simpler numerical experiment by E. Baratchart during his internship [53], see Fig. 3.

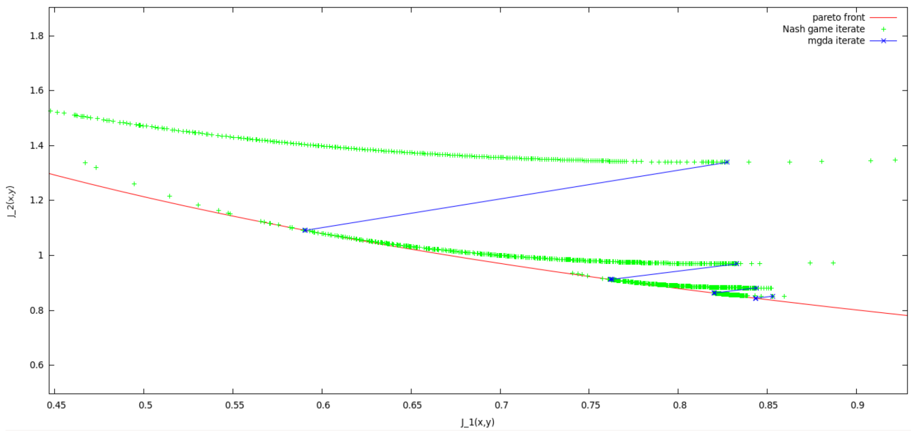

Figure 3. Combination of cooperative and competitive optimization algorithms: in red the Pareto set, in blue MGDA steps directed to the Pareto set, in green steps by Nash games with split of territory tangent to the Pareto set.

Our approach to *cooperative optimization* is based on a result of convex analysis established for a general unconstrained multiobjective problem in which all the gradients are assumed to be known. The theorem [58] states that in the convex hull of the gradients, there exists a unique vector of minimal norm, ω; if it is nonzero, the vector ω is a descent direction common to all criteria; otherwise, the current design point is Pareto-optimal. This result led us to generalize the classical steepest-descent algorithm by using the vector ω as search direction. We refer to the new algorithm as the multiple-gradient descent algorithm (MGDA). The MGDA yields to a point on the Pareto set, at which a competitive optimization phase can possibly be launched on the basis of the local eigenstructure of the different Hessian matrices. This general formulation fosters several connected studies detailed in 6.2.3.

6.2.2. Virtual games for coupling global to local shape optimization

Participant: Régis Duvigneau.

In several engineering problems, the system to optimize is characterized by some parameters that define global shape properties, while remaining parameters define local shape modifications. Of course, these two sets of parameters do not play the same role and have not the same impact on the cost functional value. Therefore, we are studying how to construct an efficient optimization strategy that takes benefit of this global / local splitting of parameters.

A typical aerodynamic shape optimization problem has been studied, that consists of a lift-constrained drag minimization for a transonic wing, whose sections are defined by two B-Spline curves whereas global shape characteristics are defined by five parameters (span, roottip length ratio, angle of attack, twist angle, sweep angle). It has been found that the naive simultaneous optimization of all parameters failed, due to the multimodality of the problem. Alternatively, the use of a virtual game strategy, based on a splitting between the local and global parameters, yields a satisfactory result for a moderate cost [47].

6.2.3. Multiple-Gradient Descent Algorithm (MGDA)

Participants: Jean-Antoine Désidéri, Régis Duvigneau, Adrien Zerbinati.

6.2.3.1. Basic experiments and validation

In multi-objective optimization, the knowledge of the Pareto set provides valuable information on the reachable optimal performance. A number of evolutionary strategies (PAES, NSGA-II, etc), have been proposed in the literature and proved to be successful to identify the Pareto set. However, these derivative-free algorithms are very demanding in terms of computational time. Today, in many areas of computational sciences, codes are developed that include the calculation of the gradient, cautiously validated and calibrated.

In [50], MGDA has been tested over a number of classical multiobjective-optimization testcases, and found successful to converge to Pareto-optimal solutions in situations of either convex or concave Pareto sets. Additionally, MGDA and PAES [61] were found to have complementary merits, making a hybrid method promising.

6.2.3.2. Metamodel-supported CFD optimization by MGDA

Using MGDA in a multi objective optimization problem requires the evaluation of a large number of points with regard to criteria, and their gradients. In the particular case of a CFD problems, each point evaluation is very costly since it involves a flow computation, possibly the solution of an adjoint-equation. To alleviate this difficulty, we have proposed to construct metamodels of the functionals of interest (lift, drag, etc) and to calculate approximate gradients by local finite differences. These metamodels are updated throughout the convergence process to the evaluation of the new design points by the high-fidelity model, here the 3D compressible Euler equations.

This variant of MGDA has been tested successfully over a problem of external aerodynamic optimum-shape design of an aircraft wing consisting of reducing wave-drag, and augmenting lift. After only a few cycles of database updates, the Pareto front visibly forms, and this result is achieved at a very moderate computational cost. This variant is currently being tested and extended to an internal flow optimization problem related to an automobile air-conditioning system and governed by the Navier-Stokes equations. This more difficult problem has been proposed by Renault within the OMD2 ANR project.

6.2.3.3. MGDA in functional setting

One aspect of the theoretical result concerning the minimal-norm element ω is that, regardless the possibly-functional setting of the problem in case of a distributed system, the descent-direction ω is identified in the standard n-dimensional vector space $\mathbb{R}^n$ (n: the number of objective functions).

This observation has led to examine the application of MGDA in the functional setting of domain-decomposition methods (DDM) in which a functional criterion and a functional control can be defined at each interface independently permitting to formulate the DDM problem as a multi-objective optimization. On-going research in this area is related to the necessary preconditioning, or normalization procedure, of the gradients.

6.2.4. Flow control

Participants: Régis Duvigneau, Jérémie Labroquère.

Shape optimization methods are not efficient to improve the performance of fluid systems, when the flow is characterized by a strong unsteadiness related to a massive flow separation. This is typically the case for the flow around an automotive body or a wing in stall condition. To overcome this difficulty, flow control strategies are developed, that aim at manipulating vortex dynamics by introducing some active actuators, such as periodic blowing/suction jets. In this context, the choice of the control parameters (location, amplitude, frequency) is critical and not straightforward. Therefore, a numerical study is conducted to i) improve the understanding of controlled flows ii) develop a methodology to determine optimal control parameters by coupling the controlled flow simulation with optimization algorithms. Two research axes have been considered :

- the solution of the unsteady sensitivity equations derived from the state equations, to exhibit the dependency of the flow dynamics with respect to the control ;
- the optimization of control parameters using a statistical metamodel-based strategy. First results show the efficiency of such an approach for laminar flow problems [31], [45].

6.2.5. Optimum shape design in aerodynamics by the adjoint method

Participants: Manuel Bompard, Sébastien Bourasseau, Jean-Antoine Désideri, Jacques Peter [Research Engineer, ONERA/DSNA].

At ONERA, compressible flow simulations governed by the Euler or Navier Stokes (RANS) equations are conducted with the software elsA [57] that admits both structured and unstructured-grid formulations. Local aerodynamic optimizations are made with a version that includes the calculation of the shape gradient via the solution of an adjoint equation. The discrete adjoint is calculated formally step-by-step to include the various derivative terms involved, and is being enhanced gradually to account for more complex models. In particular, for RANS computations, this gradient today includes the differentiation of the turbulence model.

6.2.5.1. Metamodels including derivative informatio.

In this context, to alleviate the cost of an optimum-shape design in aerodynamics, M. Bompard in his thesis [26], has examined how metamodels, firstly based on functional values only, could be used to determine shortcuts in the convergence process. Second, when the gradient w.r.t. the design parameters is known, the gradients of functionals of interest, that is, most commonly, aerodynamic coefficients, are calculated. Thus, these derivative informations can also used to construct more elaborate metamodels. Such constructions have also been studied systematically and used efficiently in global optimizations [38]; in particular co-Kriging and Support-Vector Regression, for which a technique to adjust automatically the free parameters has been proposed based on a simplification of the *leave-one-out* test.

6.2.5.2. Parameterization-free local optimization

When the derivatives of the functionals w.r.t. the volume geometry, dJ/dX, have been calculated, it is also possible to calculate the gradient w.r.t. surface coordinates, dJ/DS. Since the surface deformation steers the entire mesh movement, often through analytical dependencies, M. Bompard [26] has also examined how could dJ/dS be used directly in a local aerodynamic optimization. However, it is well-known that the distribution of dJ/dS is very irregular, and its usage in the optimization loop necessitates that adequate smoothing procedures be elaborated. Partial success was achieved in this area, still subject to research.

6.2.6. Aero-structural optimization

Participants: Gérald Carrier [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Imane Ghazlane.

In industry, aircraft wings are designed by accounting for several multidisciplinary couplings. Certainly of greatest importance is the coupling, or concurrency, between aerodynamic optimization and structural design. At ONERA, in the former thesis of M. Marcelet, the aerodynamic gradient has been extended to account for (the main terms of) static fluid-structure interaction, commonly referred to as the “aeroelastic gradient”.

In her thesis, I. Ghazlane has extended M. Marcelet's work to take into account, in the aeroelastic gradient, the terms originating from the differentiation of the wing-structural model. In this development, the wing structure is treated as an equivalent Euler-Bernoulli beam. These formal extensions have been validated by an extensive experimentation. Additionally, special post-processing procedures are applied to evaluate accurately the various physical contributions to drag. As a result, the numerical tools necessary to conduct a very realistic aircraft wing optimization are now set up and are being exploited [39]. It is also envisaged to conduct a two-objective optimization (drag and mass reduction) via a Nash game using our optimization platform FAMOSA.

6.2.7. Sonic boom reduction

Participants: Gérald Carrier [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Andrea Minelli, Itham Salah El Din [Research Engineer, ONERA/DAAP].

When an aircraft flies at supersonic speed, it generates at ground level an N-shaped shock structure which can cause serious environmental damage ("sonic boom"). Thus a problem of interest in aerodynamic optimization is to design such an aircraft to reduce the intensity of the sonic boom while maintaining the aerodynamic performance (drag minimization under lift constraint). Andrea Minelli's aimed at contributing to this two-discipline optimization problem. In the first part of his work, an inverse problem has been formulated and solved for "shaped sonic boom" and found in excellent agreement with the George-Seebass-Darden theory [60] for the calculation of the Whitham function corresponding to the lowest-boom (axisymmetric) shape. The method is currently being extended to account for more general geometries. Besides, aero-acoustic optimizations have been realized successfully by coupling the aerodynamic optimizer (based on Euler calculations by the elsA sofware) with the sonic-boom computation in a Nash game formulation. These experiments, conducted with our optimization platform FAMOSA, have demonstrated that starting from the shape optimized aerodynamically, one could retrieve smoothly a shape corresponding to nearly-optimal sonic-boom reduction.

6.2.8. Helicopter rotor blade optimization in both situations of hovering and forward flight

Participants: Michel Costes [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Arnaud Le Pape [Research Engineer, ONERA/DAAP], Enric Roca Leon.

E. Roca Leon has recently started at ONERA a CIFRE thesis supported by EUROCOPTER, Marignane. This thesis follows the doctoral thesis of A. Dumont in which the adjoint-equation approach was used to optimize a rotor blade in hovering flight. The goal of this new thesis is to solve a two-objective optimization problem in which the hovering-flight criterion is considered preponderant, but a new criterion that takes into account the forward-flight situation is also introduced, concurrently. The thesis work includes the set up of a hierarchy of models from low to high fidelity, in order to calibrate appropriate functional criteria. Secondly, our Nash game approach to competitive optimization will be implemented, using our optimization platform FAMOSA, and comparisons with the results by A. Dumont will be made.

6.2.9. Optimum design in naval hydrodynamics

Participants: Régis Duvigneau, Louis Blanchard.

Naval hydrodynamics field has recently shown a growing interest for optimum design methods. The computational context is especially complex because it implies unsteady two-phase turbulent flows, with possibly very high Reynolds number (up to 10^9). The use of automated design optimization methods for such problems requires new developments to take into account the large CPU time necessary for each simulation and the specificity of the geometries considered.

In collaboration with GALAAD Project-Team, some developments have been initiated on the geometrical modeling of hull shapes by parametric surfaces. The objective is to be able to modify existing hull shapes by controlling a small number of parameters, that are meaningful for naval architects. Two testcases are considered: the bow shape for trawler ships (see Fig. 4) and the whole hull shape for canoes, in collaboration with the Fédération francaise de Canoe-Kayak.

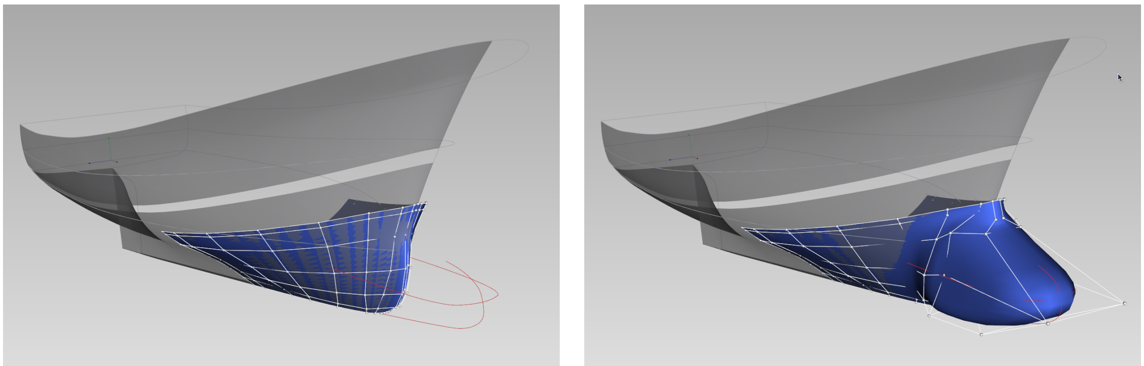

Figure 4. Initial shape (left) and deformed shape to generate a bow (right) for the trawler ship, to reach two line targets (in red).

6.3. Optimum design in structural mechanics

6.3.1. Shape Optimization in Multidisciplinary Non-Linear Mechanics

Participants: Aalae Benki, Jean-Antoine Désidéri, Abderrahmane Habbal.

In collaboration with the ArcelorMittal's Center for Research in Automotive and Applications, we study the multidisciplinary shape and parameter design of highly non linear mechanical 2D and 3D structures. We have developed methods adapted to the approximation of Pareto Fronts such as Normal Boundary Intersection NBI and Normalized Normal Constraint Method NNCM. Due to the time consuming cost evaluation, the use of cheap to evaluate surrogate models is mandatory. We have studied the consistency of the approach NBI or NNCM plus surrogates, which turned out to be successful for a broad panel of standard mathematical benchmarks. The application of this approach for the case of beverage cans which undergo elastoplastic deformation under high pressure is ongoing.

6.3.2. Optimization of Addendum Surfaces in Stamping

Participants: Fatima Zahra Oujebbour, Jean-Antoine Désidéri, Abderrahmane Habbal.

Within the OASIS Consortium (ArcelorMittal, ErDF, INRIA, UTC, EURODECISION, ESILV, NECS, Delta-CAD, SCILAB-DIGITEO), Opale Project leads the Optimization task. Our aim is to develop decentralized decision-making algorithms dedicated to find efficient solutions (Pareto optimal) in a complex multidisciplinary framework (forming, stamping, welding non-linear processes, spring-back, vibration, in-function linear processes, crash and fatigue non linear and non differentiable processes) for several (between three and five) criteria. An important difficulty when trying to identify the Pareto Front, even when using adapted methods such the Normal Boundary Intersection, is that the criteria involved (thanks to the high nonlinearity in the mechanical models) exhibit many local optima. So one must use global optimization methods. We have studied the hybrid approach Simulated Annealing with Simultaneous Perturbation SASP for a suite of mathematical test-cases. To envisage the application of our method to the complex CPU time consuming stamping process, we lead an intermediate phase dedicated to the validation of the SASP method for the minimization of the spring-back that follows the stamping of a metal sheet, the design variable being the thickness distribution.

6.4. Application of shape and topology design to biology and medicine

6.4.1. Mathematical modeling of dorsal closure DC

Participants: Abderrahmane Habbal, Luis Almeida [University of Nice-Sophia Antipolis], Patrizia Bagnerini [Genova University], Fanny Serman [University of Nice-Sophia Antipolis], Stéphane Noselli [University of Nice-Sophia Antipolis], Glenn Edwards [Duke University].

A mathematical model for simulation of actin cable contraction, during wound closure for Drosophila embryo, which contains an extra term in addition to the curvature flow is developed. The basic mathematical model introduced and validated in [27] is extended in order to include the non-homogeneous wound healing or non-homogeneous dorsal closure [52].

6.5. Particular applications of simulation methods

6.5.1. Analysis of a two-level parameterization optimization for antenna design

Participants: Benoît Chaigne [Doctoral student, 2007-2010], Jean-Antoine Désideri.

Similar to the discretization of ordinary or partial differential equations, the numerical approximation of the solution of an optimization problem is possibly subject to numerical stiffness. In the framework of parametric shape optimization, hierarchical representations of the shape can be used for preconditioning, following the idea of Multigrid (MG) methods. By analogy with the Poisson equation, which is the typical example for linear MG methods, we have addressed a parametric shape inverse problem. The ideal cycle of a two-level algorithm can be defined and adapted to shape optimization problems that require appropriate transfer operators. With the help of a symbolic calculus software we have shown that the efficiency of an optimization MG-like strategy is ensured by a small dimension-independent convergence rate. Numerical examples are worked out and corroborate the theoretical results. Applications to antenna design have been realized. Finally, some connections with the direct and inverse Broyden-Fletcher-Goldfarb-Shanno preconditioning methods have been shown [29].

6.5.2. Mesh qualification

Participants: Jean-Antoine Désideri, Maxime Nguyen, Jacques Peter [Research Engineer, ONERA/DSNA].

M. Nguyen Dinh is conducting a CIFRE thesis at ONERA supported by AIRBUS France. The thesis topic is the qualification of CFD simulations by anisotropic mesh adaption. Methods for refining the 2D or 3D structured mesh by node movement have been examined closely. Secondly, it is investigated how could the local information on the functional gradient $\|dJ/dX\|$ be exploited in a multi-block mesh context. This raises particular questions related to conservation at the interfaces.

6.5.3. Hybrid meshes

Participants: Sébastien Bourasseau, Jean-Antoine Désideri, Jacques Peter [Research Engineer, ONERA/DSNA], Pierre Trontin [Research Engineer, ONERA/DSNA].

S. Bourasseau has started a CIFRE thesis at ONERA supported by SNECMA. The thesis is on mesh adaption in the context of hybrid meshes, that is, made of both structured and unstructured regions. Again, the aim is to exploit at best the function gradient provided by the adjoint-equation approach. Preliminary experiments have been conducted on geometries of stator blade yielding the sensitivities to global shape parameters.

6.5.4. Nash game approach to image processing

Participants: Abderrahmane Habbal, Rajae Aboulaich [Mohamed V University of Rabat], Maher Moakher [University of Tunis], Moez Kallel [University of Tunis], Anis Theljani [University of Tunis].

We have started in 2011 to study the application of game modeling to image processing problems. We propose an original game theory approach to simultaneously restore and segment noisy images [56]. We define two players: one is restoration, with the image intensity as strategy, and the other is segmentation with contours as strategy. Cost functions are the classical relevant ones for restoration and segmentation, respectively. The two players play a static game with complete information, and we consider as solution to the game the so-called Nash Equilibrium. For the computation of this equilibrium we present an iterative method with relaxation. The results of numerical experiments performed on some real images show the relevance and efficiency of the proposed algorithm. Based on a similar idea, we formulated well known data completion (Cauchy) problems for Laplace equation as Nash games [55] and obtained results of existence, uniqueness and stability of a Nash equilibrium which turns out to be the Cauchy solution when the Cauchy data are compatible. With A. Theljani, we study the extension of the Nash data completion approach to nonlinear parabolic equations with application to image impainting.

6.6. Isogeometric analysis and design

Participants: Louis Blanchard, Régis Duvigneau, Bernard Mourrain [Galaad Project-Team], Gang Xu [Galaad Project-Team].

Design optimization stands at the crossroad of different scientific fields (and related software): Computer-Aided Design (CAD), Computational Fluid Dynamics (CFD) or Computational Structural Dynamics (CSM), parametric optimization. However, these different fields are usually not based on the same geometrical representations. CAD software relies on Splines or NURBS representations, CFD and CSM software uses grid-based geometric descriptions (structured or unstructured), optimization algorithms handle specific shape parameters. Therefore, in conventional approaches, several information transfers occur during the design phase, yielding approximations that can significantly deteriorate the overall efficiency of the design optimization procedure. Moreover, software coupling is often cumbersome in this context.

The isogeometric approach proposes to definitely overcome this difficulty by using CAD standards as a unique representation for all disciplines. The isogeometric analysis consists in developing methods that use NURBS representations for all design tasks:

- the geometry is defined by NURBS surfaces;
- the computation domain is defined by NURBS volumes instead of meshes;
- the solution fields are obtained by using a finite-element approach that uses NURBS basis functions
- the optimizer controls directly NURBS control points.

Using such a unique data structure allows to compute the solution on the exact geometry (not a discretized geometry), obtain a more accurate solution (high-order approximation), reduce spurious numerical sources of noise that deteriorate convergence, avoid data transfers between the software. Moreover, NURBS representations are naturally hierarchical and allows to define multi-level algorithms for solvers as well as optimizers.

In this context, some research axes have been developed in collaboration with GALAAD Project-Team:

- Methods for adaptive parameterization including a posteriori error estimate for elliptic problems [36], [35], [43] ;
- Numerical schemes based on Spline functions for 2D inviscid compressible flow simulations ;
- Optimization methods for structural elasticity, based on shape-gradient concept, and fluid-structure interactions [48] (in collaboration with Technical University of Munich).

6.7. Resilient workflows for distributed multidiscipline optimization

Participants: Toan Nguyen, Laurentiu Trifan.

A distributed platform based on the YAWL workflow management system has been designed and implemented to deploy HPC applications on the Grid5000 network infrastructure. The goal is to provide a generic environment for the design of complex applications that require HPC resources for large-scale fault-tolerant applications, see Fig. 2 and [40].

The platform provides application-level fault-tolerance, i.e., resilience, in order to restart the workflow execution whenever abnormal behavior or system-level errors occur. This allows a variety of errors to be taken into account, ranging from execution time-outs to out-of-bounds parameter values to be managed, with the help of user intervention when necessary [41].

The error management procedure uses exception handlers in YAWL to trigger the appropriate corrective actions, which are defined by rules invoking the adequate compensating workflows. Once defined, this can be made transparent to the users [42].

An original scheme based on asymmetric checkpoints has be designed is order to reduce overhead in both checkpointing and application restarts. It minimizes the number of required checkpoints created based on default rules and user-specific needs.

The platform is currently developed in Java on Linux workstations and should be portable on Windows and MacOS, although this has not been tested yet.

Examples are deployed on the Grid5000 national network infrastructure using the OMD2 test-cases (e.g., vehicle air-conditioner pipe optimization). The goal is here to provide a demonstrator platform that deploys large-scale optimization applications involving several (typically over five) HPC clusters distributed on the Grid5000 network. The coarse-grain definition of the application is defined by a workflow that monitors the distributed execution of the parallel component codes on the various clusters, providing resilience capabilities in case of system and application errors, see Fig. 5.

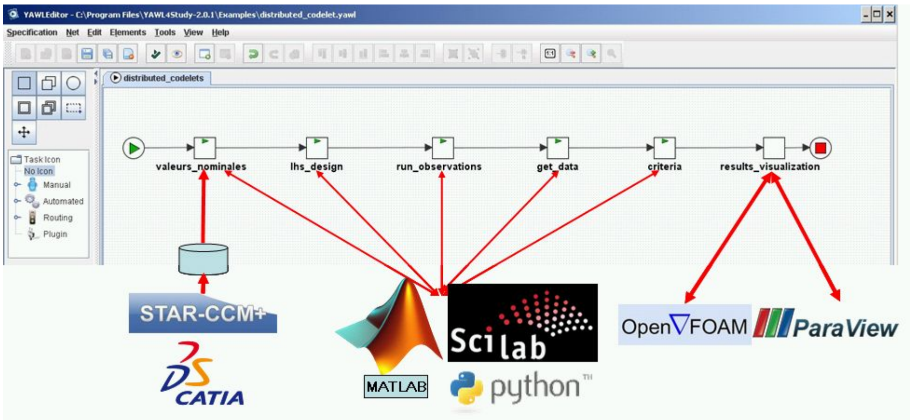

Figure 5. Application definition using YAWL.

7. Contracts and Grants with Industry

7.1. Contracts with Industry

ArcelorMittal-INRIA industrial contract n. 5013 : Opale started a thorough collaboration in optimal design of high performance steel with the mentioned world leader industrial.The present contract has three years duration and funds a Ph.D. thesis and Research financial support.

7.2. National Initiatives

7.2.1. Project "Bulbe"

This project is funded by the Ministry of Fishing and gathers OPALE Project-Team, K-Epsilon company (specialized in CFD for naval hydrodynamics) and PROFIL company (naval architect). The objective is to design and optimize bow shapes for trawler ships, in order to reduce the fuel consumption during fishing campaigns. Our role is to construct an automated optimization loop to improve bow efficiency, on the basis of CFD tools provided by K-Epsilon company and naval architect recommendations.

7.2.2. Project "OASIS"

The OASIS project, Optimization of Addendum Surfaces In Stamping, is an R&D consortium (CS, Arcelor-Mittal, ErDF, INRIA, UTC, EURODECISION, ESILV, NECS, DeltaCAD, SCILAB-DIGITEO) of the Pole Systemtic Paris-Region dedicated to develop an optimal design framework (methods-software platforms-applications) for stamping processes. The EPI OPALE/INRIA is the leader within the consortium for the Optimization work-package (one of six WP). The OASIS project yields 2.4 Meuro total financial support (one Ph.D thesis, two post-doctoral positions and 12 months internship for OPALE).

7.2.3. Project "OMD2", Optimisation Multi-Disciplinaire Distribuée (Distributed Multidisciplinary Optimization)

This project funded by ANR deals with the development of a software platform devoted to Multidisciplinary Design Optimization (MDO) in the context of distributed computing.

The notion of optimization platform based on distributed and parallel codes is undertaken with a distributed workflow management system running on a grid infrastructure using the ProActive middleware from INRIA, in collaboration with the OASIS project at INRIA Sophia-Antipolis.

Renault is the coordinator of this project, which involves also EMSE, ENS Cachan, EC Nantes, Université de Technologie de Compiègne, CD-Adapco, Sirehna, Activeon, and INRIA project TAO, OASIS and OPALE. This contract provides the grant supporting two PhD theses (A. Zerbinati and L. Trifan)

7.2.4. Project "Optican"

This project is funded by the Ministry of sports and aims at improving the efficiency of canoes, in the perspective of London Olympic Games in 2012.

7.3. European Initiatives

7.3.1. FP7 Projects

7.3.1.1. EXCITING

Title: Exact Geometry Simulation for Optimized Design of Vehicles and Vessels

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: October 2008 - Mars 2012

Coordinator: Jozef Kepler universitet (Austria)

Others partners: SINTEF (SW), SIEMENS (GER), NTUA (GR), HRS (GR), TUM (GER), HYDRO (AUS), DNV (NOR)

See also: http://exciting-project.eu/

Abstract: The objective is to develop simulation and design methods and software based on the isogeometric concepts, that unify Computer-Aided Design (CAD) and Finite-Elements (FE) representation bases. Applications concern hull shape, turbine and car structure design.

7.3.1.2. MARS

Title: Manipulation of Reynolds Stress

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: October 2010 - September 2013

Coordinator: CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA (Spain)

Others partners: USFD (UK), AIRBUS (SP), FOI (SW), ALENIA (IT), DLR (GER), CNRS (FR), DASSAULT (FR), NUMECA (BEL), UNIMAN (UK), EADS (UK)

See also: http://www.cimne.com/mars/

Abstract: The objective is to study flow control devices for aeronautical applications. This project gathers twelve European partners and twelve Chinese partners for a common work that includes both experimental and numerical studies. Opale Project-Team is in charge of developing numerical algorithms to optimize flow control devices (vortex generators, synthetic jets).

7.3.1.3. GRAIN

Title: GReener Aeronautics International Networking

Type: CAPACITIES (TRANSPORTS)

Instrument: Coordination and Support Action (CSA)

Duration: October 2010 - September 2012

Coordinator: CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA (Spain)

Others partners: AIRBUS (SP), ALENIA (I), EADS-IW (F), Rolls-Royce (UK), INGENIA (SP), NUMECA (B), U. SHEFFIELD (UK), U. BIRMINGHAM (UK), CIRA (I), VKI (B), AIRBORNE (NL), LEITAT (SP), CERFACS (F), U. CRANFIELD (UK), CAE (CN), GTE (CN), ARI (CN), FAI (CN), ASRI (CN), SAERI (CN), BIAM (CN), ACTRI (CN), BUAA (CN), NPU (CN), PKU (CN), NUAA (CN), ZJU (CN).

See also: http://www.cimne.com/grain

Abstract: The GReener Aeronautics International Networking (GRAIN) is a 24 month project co-funded by the 7th Framework Programme of the European Community (EC) and by the Chinese Ministry of Industry and Information Technology (MIIT). It is managed by the European Commission as a Coordination and Support Action. The main objectives of GRAIN are to identify and assess the future development of large scale simulation methods and tools needed for greener technologies reaching the Vision 2020 environmental goals. GRAIN will prepare the R&T development and exploitation with new large scale simulation tools used on distributed parallel environments to deeper understand and minimize the effects of aircraft/engine design on climate and noise impact. This objective can be met by supporting joint Europe-China networking actions for defining the necessary technologies to improve green aircraft performance.

7.3.1.4. TraM3

Title: TRaffic Management by Macroscopic Models

Type: IDEAS

Instrument: ERC Starting Grant (Starting)

Duration: October 2010 - September 2015

Coordinator: INRIA (France)

See also: http://www-sop.inria.fr/members/Paola.Goatin/tram3.html

Abstract: The project intends to investigate traffic phenomena from the macroscopic point of view, using models derived from fluid-dynamics consisting in hyperbolic conservation laws. The scope is to develop a rigorous analytical framework and fast and efficient numerical tools for solving optimization and control problems, such as queues lengths control or buildings exits design.

7.3.2. Collaborations in European Programs, except FP7

Program: PHC Polonium

Project acronym: CROM3

Project title: Crowd Motion Modeling and Management

Duration: jan. 2011 - dec. 2012

Coordinator: P. Goatin (France), M.D. Rosini (Poland)

Other partners: ICM, Warsaw University (Poland)

Abstract: The aim of this collaboration is to provide new analytical and numerical tools for solving control and optimization problems arising in pedestrian traffic management. Our scope is to develop a rigorous analytical framework and fast and efficient numerical tools for solving optimization and control problems, such as buildings exits design. This will allow to elaborate reliable predictions and to optimize traffic fluxes. To achieve this goal, we will study in details the structure of the solutions of the partial differential equations modeling traffic dynamics, in order to construct ad hoc methods to tackle the analytical and numerical difficulties arising in this study.

7.3.3. Major European Organizations with which you have followed Collaborations

Brescia University, Mathematics Department, Italy.

Analytical and numerical study of conservation laws with application to traffic modeling.

Jyväskylä University, Mathematics and Information Technology (MIT), Finland.

Numerical simulation and optimization.

7.4. International Initiatives

7.4.1. INRIA International Partners

Montreal University, Centre de Recherches Mathématiques CRM, Canada.

Shape and geometries (M. Delfour and J.-P. Zolésio).

7.4.2. Visits of International Scientists

7.4.2.1. Internship

Jihed Joobeur (from Mar 2011 until Aug 2011)

Subject: Crowd data collection from video recordings

Institution: Ecole Nationale d'Ingénieurs de Tunis (ENIT) (Tunisia)

7.4.3. Participation In International Programs

- Euromed 3+3 Project SCOmu 2009-2011 :

  Opale is the French coordinator for the project "Scientific Computing and Multidisciplinary Optimization" (SCOMU), a Euro-Mediterranean Euromed 3+3 program. The project SCOMU involves institutions from France (INRIA, Opale Project, Nice Sophia Antipolis University), Italy (University of Genova), Spain (University of Corogna), Tunisia (ENIT, Tunis) and Morocco (Ecole Mohammedia, University Mohamed V, Rabat). The project is a three-year financed action. The SCOmu project has successfully allowed researchers from the Maghreb and Euro-Mediterranean regions to exchange their modeling and analysis skills in the fields of numerical analysis, optimization and game theory. The partner teams developed applications of game theory in new areas which have strategic interests such as imaging, mathematical finance, structural mechanics and mathematics for life sciences.
- LIRIMA Team ANO 2010-2013 :

  The agreement governing the creation of the International Laboratory for Research in Computer Science and Applied Mathematics (LIRIMA) was signed on 24th November 2009 in Yaoundé. LIRIMA enables cooperation between INRIA research teams and teams in Africa (Sub-Saharan Africa and the Maghreb) to be reinforced. It is the continuation of the major operation undertaken by the SARIMA program (2004-08 – Priority Solidarity Fund created by the French Ministry of Foreign & European Affairs). The LIRIMA team ANO : Numerical analysis of PDEs and Optimization is a partnership between Opale project and the EMI engineering college, Rabat / National Centre for Scientific and Technical Research (CNRST) Morocco. The Team leader is Prof. Rajae Aboulaïch, EMI.

8. Dissemination

8.1. Animation of the scientific community

- J.-A. Désidéri is appointed part-time by ONERA (Numerical Simulation and Aeroacoustics Department, DSNA-Châtillon, and Applied Aerodynamics Department, DAAP-Meudon). This primarily results in the supervision of theses in computational fluid dynamics and optimization. This year, M. Bompard defended his thesis and five other theses are in progress. This supervision stimulates a scientific cooperation between our laboratories at both levels of senior researchers (organization of seminars and a short-course of continuing education, multi-disciplinary prospective) and doctoral students (participation in technical brainstormings, exchange of software, etc).
- J.-A. Désidéri and J. Peter (ONERA/DSNA) have been the coordinators of the continuing education short course: *Verification of numerical simulations in continuous mechanics. Notion of Validation* at *Collège de Polytechnique*, June 7-8, 2011. At this occasion, J.-A. Désidéri gave the seminar: *Analysis of approximation errors in classical PDE problems with application to continuous mechanics* (4.5 hrs).

8.2. Participation in scientific committees

- R. Duvigneau is member of the CFD (Computational Fluid Dynamics) committee of ECCOMAS (European Community for Computational Methods in Applied Science).
- R. Duvigneau is member of CNU (Conseil National des Universités) for the 26th section (applied mathematics and application of mathematics).
- J.-P. Zolésio is chair of WG 7.2 on Computational Techniques in Distributed Systems, International Federation for Information Processing (IFIP) TC7: System Modeling and Optimization.

8.3. Teaching

Licence: Introduction to Numerical Analysis, 71,5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri, A. Zerbinati).

Licence: Numerical Methods I, 19.5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri).

Licence: Solid Mechanics (statics, kinematics, dynamics, energetics), 45.5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (F. Z. Oujebbour).

Licence: Linear Systems, 39 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (R. Duvigneau).

Licence: Partial Differential Equations, 36 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (R. Duvigneau).

Master: Advanced Optimization, 54 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri, R. Duvigneau, A. Habbal).

Master: Conservation laws and traffic flow models, 32 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (P. Goatin).

PhD & HdR :

PhD : Manuel Bompard, *Modèles de substitution pour l'optimisation globale de forme en aérodinamyque et méthode locale sans parétrisation*, University of Nice Sophia Antipolis, December 2011, supervisors: J. A. Desideri and Jacques Peter (ONERA/DSNA).

PhD in progress : Sébastien Bourasseau, *Méthodes de raffinement de maillages non structurés basées sur le vecteur adjoint pour le calcul de coefficients aérodynamiques*, October 2011, Supervisors: Jean-Antoine Désidéri and Jacques Peter (ONERA/DSNA).

PhD in progress : Aalae Benki, *Optimisation concurrente de forme de coque mince en régimes élastoplastique et de crash*, October 2010, supervisor: A. Habbal.

PhD in progress : Maria Laura Delle Monache, *Traffic flow modeling by conservation laws*, October 2011, supervisor: P. Goatin

PhD in progress : Samira El Moumen, *Portfolio Management in Finance*, October 2009, supervisors: R. Aboulaich, R. Ellaia (Rabat) and A. Habbal.

PhD in progress : Imane Ghazlane, *Optimisation aérodynamique et structurale de la voilure d'un avion de transport avec la méthode adjointe*, October 2009, Supervisors: Jean-Antoine Désidéri and Gérald Carrier (ONERA/DAAP).

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